Briefing to the ESSAAC
Technology Subcommittee (TSC)

on

Radar Electronics Technology Requirements & Roadmaps

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ESTO

Introduction

- Process to Derive Technology Requirements
- Measurement Types
- Technology Needs
- Example Requirements & Roadmaps: Large Aperture L-band SAR
- Integrated Radar Roadmap
- Concluding remarks

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Process to Derive Radar Technology Requirements

- ESTO formed a Radar/Radiometer Working Group whose charter is to validate the ESTIPS database and then generate technology roadmaps and development plans
- Members of the working group include JPL, GSFC, university and industry participation
- 42 radar measurement scenarios were reviewed
  - Measurement scenarios/parameters were mapped to science roadmap
  - Technology challenges were assessed
    - Performance or environmental requirements
    - Resource constraints (mass, power, cost)
    - Technology survey
  - Scenarios were classified
    - Enabling, Enhancing, Mature, Obsolete
  - Prioritized technology needs
    - Focus on technologies enabling multiple high-priority measurements

Measurement Types

Measurement Type	Criticality	Utility (scenario ID)
Large aperture SAR	Enabling	MEO/GEO L-band InSAR (45, 46) UHF/VHF Deep Soil Moisture (112)
X-, Ku- & Ka-band Single-Pass Interferometers (using phased array antennas)	Enabling	100, 28?, 93, 161A, 163
Millimeter Wave Atmospheric Radars using phased array antennas (Ka-, W-band, G-band)	Enabling	75, 76, 159, 160
Moderate aperture SAR	Enhancing	22, 105, 92, 19, 44a, 44b, C1, 97, 158, 162
Millimeter Wave Atmospheric Radars (Ka-, W-band)	Enhancing	68, 142, 154
MEO Scatterometer	Enhancing	148
Misc.	Enhancing	O2, 30, 51
Airborne/Suborbital Platforms	Enhancing	161B, 161C, 47, 157
Mature measurement scenarios	Mature technology	102, 151, 155, 29, 61, 90, 156
Obsolete measurement scenarios	Obsolete	103, 104

Measurement Types

Primary areas recommended for technology investment:

1. Large Aperture SAR technologies
   - Focuses on electronics required for lightweight ESA (particularly L-band and Ku-band)
   - Will also benefit near-term SAR missions (of moderate aperture size)

2. X, Ku, Ka-band Interferometers
   - Focuses on developing electronics for phase-stable ESA
   - X-band is lower priority since significant investment by DoD

3. Millimeter Wave Atmospheric Radar
   - Focuses on millimeter wave ESA (Ka, W, G-band)

Technology Challenges

Lower Frequency
(UHF, P-band)

Large Deployable Antennas

Higher Orbits
(MEO, GEO)
(L-, Ku-, Ka-band)

Large Deployable Structures

- *Stiffness*
- *Surface flatness*
- *Lightweight*
- *Stowed volume*

- **Inflatables**
- **Deployables**
- **Interferometric masts (>100m)**

Antenna Aperture

- *Frequency/BW*
- *Scanning*
- *Multiple beams*
- *Lightweight materials*

- **Phased Array**
- **Phased-Array Feed**
- **Reflect-array**
- **Large Reflector**
- **Large Rotating Reflector**
- **Multiple-feeds or shared-aperture**

Electronics

- *Frequency/BW*
- *Tx Power*
- *Phase stability*
- *Low DC power*
- *Low mass*
- *Low cost*
- *Rad-Hard*

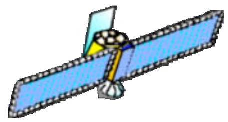
- **T/R modules**
- **MMIC devices**
- **High pwr transmitters**
- **Chirp generators**
- **Digital receivers**
- **Thermal mgmt**
- **Signal distribution**

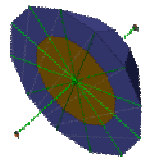
System

- *Wide-area imaging*
- *Resolution improvement*
- *Enhanced measurement*
- *Cost reduction*

- **Metrology/Calibration**
- **Wavefront sensing and control**
- **Digital beamforming**
- **Manufacturability**

Technology Improvements





SIR-C/SRTM
(1994/1999)
L & C-Band SAR
Low LEO
Elect Steered Array (ESA)
40 MHz BW
5KW transmit power
$\sim 40m^2$
>20 kg/m^2

Current SOA
(2004)
L-Band SAR
High LEO
Elect Steered Array (ESA)
80 MHz BW
5-8KW transmit power
+/- 15 deg steering in 2D
$\sim 50m^2$
8-12 kg/m^2

Future Goal
(2014)
L-Band SAR
MEO and GEO
Elect Steered Array (ESA)
>80 MHz BW
65KW transmit power
+/-30 deg steering in 2D
TTD elements
DBF
Metrology & Calibration
$\sim 700m^2$
<2 kg/m^2

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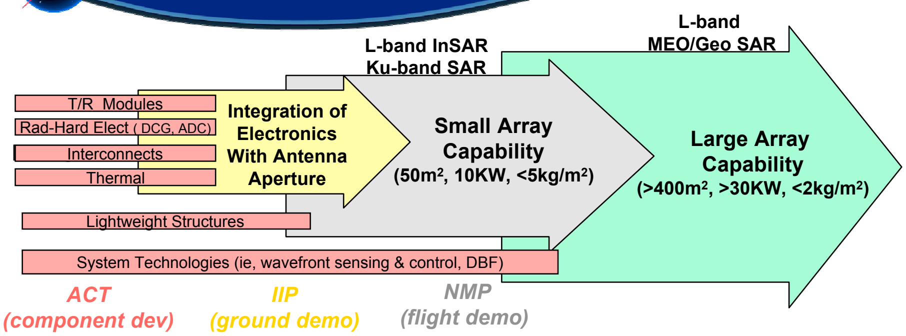
Large Aperture SAR Technologies



- Large aperture Electronically Steered Arrays (ESAs) require lightweight, low power, highly integrated electronics compatible with lightweight apertures and structures (e.g., membrane antennas and inflatable structures).
- Specific components include high-efficiency membrane compatible T/R modules and other electronics distributed on the array, technologies to attach and interconnect these components as well as thermal management technologies compatible with lightweight antennas.
- System technologies include digital beamforming and wavefront sensing and adaptive control to compensate for deformations of the large array
- Address integration of electronics by combining all component and system technologies (e.g., membrane T/R, interconnects, thermal with aperture and demonstrate DBF).

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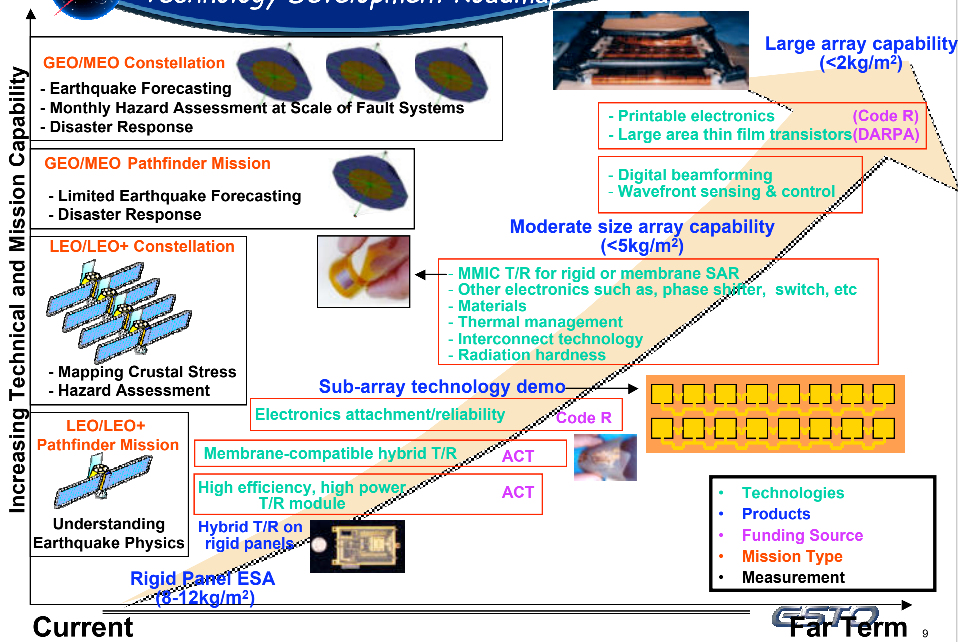
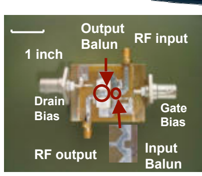
Membrane SAR Antenna Technology Development Roadmap

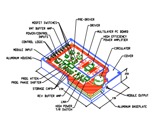


VHF/UHF/L-band High Power High Efficiency T/R Modules



35W Class-E/F PA with 66% drain efficiency at 1200 MHz

30W T/R Module Breadboard



Layout of integrated L-band T/R module

for small to moderate size array LEO SAR with antenna mass densities <8kg/m2

Current Status:

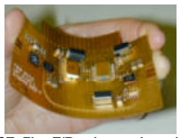
- Commercial SOA: 30W Si and GaAs, 50% eff (L-band)
- Current ACT (JPL & Caltech): 35W LD-MOS L-band Class-E/F PA, >60% efficiency, current TRL 4
  - Breadboard demo in FY03 (TRL 3)
  - Miniaturized 1st prototype in FY04 (TRL 4)
  - 2nd prototype in FY05 (TRL 5 anticipated)

Tasks needed:

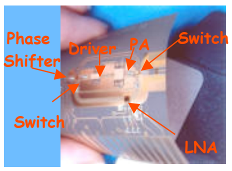
Develop T/R modules at VHF/UHF/L-band
- 5-10W T/R, for 1D and 2D full-scan ESA
- 20-40W T/R for moderate size ESA
- 50-100W T/R for limited scan or 1-axis scan

1. Increase efficiency and power density
   VHF: 200W 70% efficiency
   UHF: 100 W 70% efficiency
   L-band: 50W, 70% efficiency
2. Reduce mass to <100g
3. Address radiation hardness
4. Add BIT and telemetry
5. Reduce cost to $1K per module

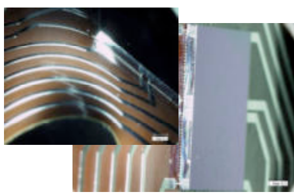
Membrane L-band T/R Modules



ACT: Flex T/R using packaged parts (functional)



ACT: T/R using flip chip attachment (non functional prototype for flip chip development)



ACT: Test die flip chip attachment reliability testing

for large array MEO/Geo SAR with antenna mass densities <2kg/m2

Current Status:

- Commercial SOA: does not exist
- Current ACT: 1W T/R using GaAs packaged parts, TRL 2
  - 1st Prototype demo (T/R only) in FY04
  - 2nd Prototype (T/R+controls) in FY05 (TRL 3 anticipated)

Tasks needed:

Develop membrane compatible T/R modules including attachment/packaging techniques and manufacturing techniques for low costs and high reliability

1. Optimize circuit design for membrane T/R
2. Improve T/R packaging and/or attachment
   a- die inside a low profile package
   b- direct attachment of die (i.e. flip chip)
3. Address radiation (through packaging) (>1MRad)
4. Increase transmit power (to 5-10W)
5. Increase efficiency (s.a. incorporating High-Eff PA)
6. Address thermal management
7. Address manufacturability, reliability
8. Add BIT and telemetry
9. Reduce cost <$500 per module

NOTE: Tasks 1-9 are not yet funded

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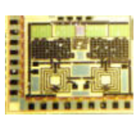
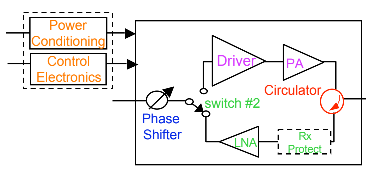
Single-Chip MMIC L-band T/R Modules

for moderate to large SAR array applications

Current Status:

Most T/R modules consist of multiple (5-6) MMICs plus discrete passives in a hybrid microcircuit. Cost is typically $1-5K in large quantities. Limited work is being done commercially to develop single chip L-band T/R modules. RF functions are being integrated into a single chip but some key components remain off-chip (circulators, control & power). Work is being done in CMOS for integrating the controls and GaAs for integrating the RF.





T/R module

Tasks needed:

Develop a fully integrated MMIC T/R module:

1. Develop individual RF components (PA, LNA, P/S, switches) using a rad-hard semiconductor process (e.g., GaAs, SOI CMOS, SiGe).
2. Develop digital control components, BIT and telemetry.
3. Integrate into a single MMIC chip.
4. Improve RF performance (inc power, efficiency, reduce NF)
5. Address radiation hardness (with minimal shielding)

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Waveform Generators

applicable to nearly all radar applications

STEL-2375B high-speed GaAs NCO-based DCG

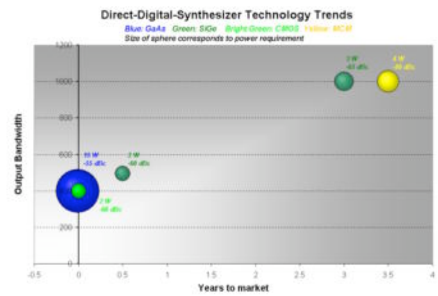
Current Status:

- STEL-2375B GaAs NCO, 400 MHz max BW, 40 dB SFDR, 15W DC. Currently at TRL 6. Prototype built and tested, airborne validated. OSTM/WSOA will raise TRL from 6 to 9 by 2008.
- AD-9858, CMOS NCO, 325 MHz max BW, 3W DC, no radiation test data available. Currently at TRL 4. In process of prototyping and radiation testing.

Tasks Needed:

Develop low power, high-speed (>300MHz BW), rad-hard (1MRad) integrated chirp generators

- Reduce power consumption <5W by 2006, <2W by 2008, <1W by 2012
- Increase speed (bandwidth) and SFDR (low sidelobes)
- Reduce mass (eg., single chip ASIC)
- Increase flexibility (arbitrary waveform generator)
- Increase radiation hardness (particularly for MEO, Geo applications)



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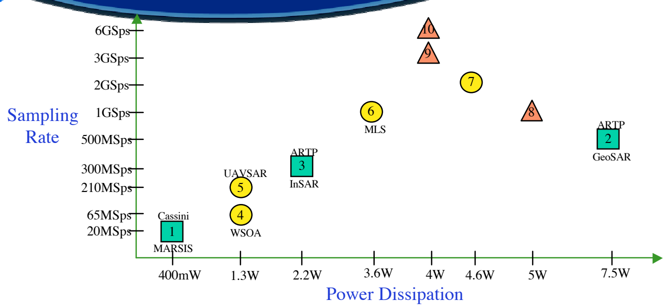
Science ADC Trends



Current/past technology, all having designs fully tested in instruments, being implemented in some present instruments.	1	Harris HS9008	8 bits	20MSps max	400 mW	Tested: No latchup TID >100 krad
	2	Maxim MX101	8 bits	500MSps max	7.5 W	Tested: Destructively failed
	3	Fairchild SPT7725	8 bits	300MSps max	2.2 W	Tested: LET > 100 TID >100 krad
Current/future technology, #6 having a design partially tested in an instrument, to be implemented in instruments over the next 5 yrs.	4	ADI AD6640	12 bits	65MSps max	1.3W	Simlarity: No latchup TID >100 krad
	5	ADI AD9430	12 bits	210MSps max	1.3W	Advanced BiCMOS, perhaps TID > 10 krad
	6	Atmel TS8388B	8 bits	1GSps max	3.6 W	Vender data: TID >150 krad
	7	Atmel TS83102G0	10 bits	2GSps max	4.6 W	Vender data: TID >150 krad
Future technology, have not been prototyped for Spaceborne radar, being implemented in higher BW instruments over the next 10 yrs.	8	Rockwell RAD010	10 bits	1GSps max	5 W	Bi-polar GaAs: s/b TID > 100 krad
	9	Rockwell RAD008	8 bits	3GSps max	4 W	Bi-polar GaAs: s/b TID > 100 krad
	10	Rockwell RAD006	6 bits	6GSps max	4 W	Bi-polar GaAs: s/b TID > 100 krad

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High-Speed Science ADC

Current Assessment

- ADC trends indicate most Code Y missions will have suitable ADC devices available **EXCEPT**
  - MEO and GEO applications requiring radiation hardening
  - MEO or GEO SAR requiring very low DC power for distributed array architectures
  - Most SAR applications would benefit from higher dynamic range (# bits)

Future Technology Development Tasks

Development of rad-hard, low power, high-speed, >8-bit ADCs.

1. Reduced power consumption for large array applications (<0.5W)
2. Radiation hardening for MEO/Geo:
   100kRad (by 2006)
   500 KRad (by 2010)
   1MRad (by 2014)
3. Increased dynamic range: Increase the number of bits (from 8-bit to 12-bit) for moderately high-speed ADC (300MHz)

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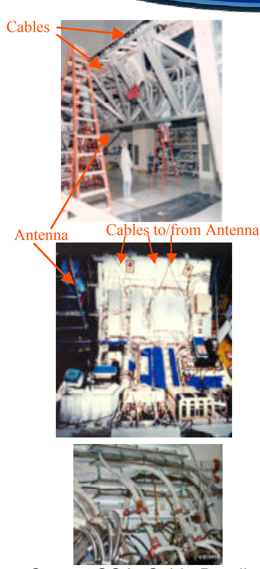
Signal Distribution & Interconnect



Current SOA: Cable Bundles

Current Status:

Large cable bundles distribute RF, power and control signals. These heavy cables are not compatible with ultra-lightweight antennas (i.e.-membrane). They are also expensive requiring extensive manual labor to build and integrate.

Tasks needed:

Development of technologies to simplify the interconnection of thousands of unit cells of ESA; significantly reduce mass and volume; develop reliable RF, control, power, and data distribution.

Sample Candidate Technologies:

1- Printed interconnects:

Challenges: Amount of current on printed lines, providing redundancy

2- Wireless interconnects:

Challenges: Bandwidth to support the amount of data, Possible RF interference

3- Optical interconnects:

Challenges: Large mass and power consumption of optical components, reliability

4- Signal multiplexing:

Challenges: system complexity, interference/isolation

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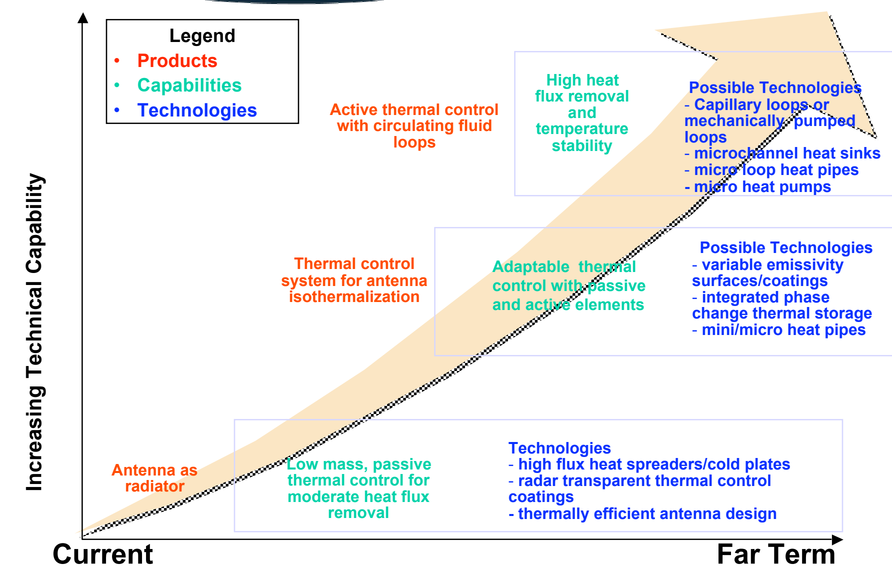
Membrane SAR Thermal Management



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Wavefront Sensing and Control

for large array MEO/Geo SAR applications

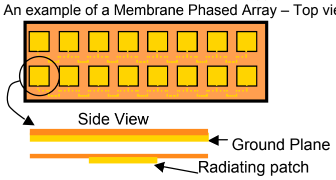
Description

- SAR measurements require the precise knowledge of the phase of the signal received. Therefore, precise knowledge of the antenna shape (surface flatness and layer separation) and phase of electronics are critical for these arrays. Thermal gradients, spacecraft motion, aging of electronics etc. all contribute to this uncertainty. Technologies for wavefront sensing and control are critical for realization of large phased arrays.

Current Status

- Some of the component technologies for sensing and control are mature however as an integrated metrology, calibration, and control system the TRL is at 1-2
- A proper ground validation system needs to be investigated for this technology

An example of a Membrane Phased Array – Top view



Array Flatness	l/20 (1.3cm)
Layer separation	1/10 of separation (1.3mm)

Tasks Needed

- Active & adaptive systems for controlling structural geometry and dynamics including measuring and correcting surface flatness, antenna to ground plane separation (See table below). Also wavefront sensing and correction due to electronics.
- Methods of creating stable wavefront & maintaining it over environmental changes such as temperature, S/C vibrations etc.
- This includes: system modeling, metrology, wavefront sensing and control, hardware and algorithm development
- Hardware and system development: Develop a ground validation system demonstration

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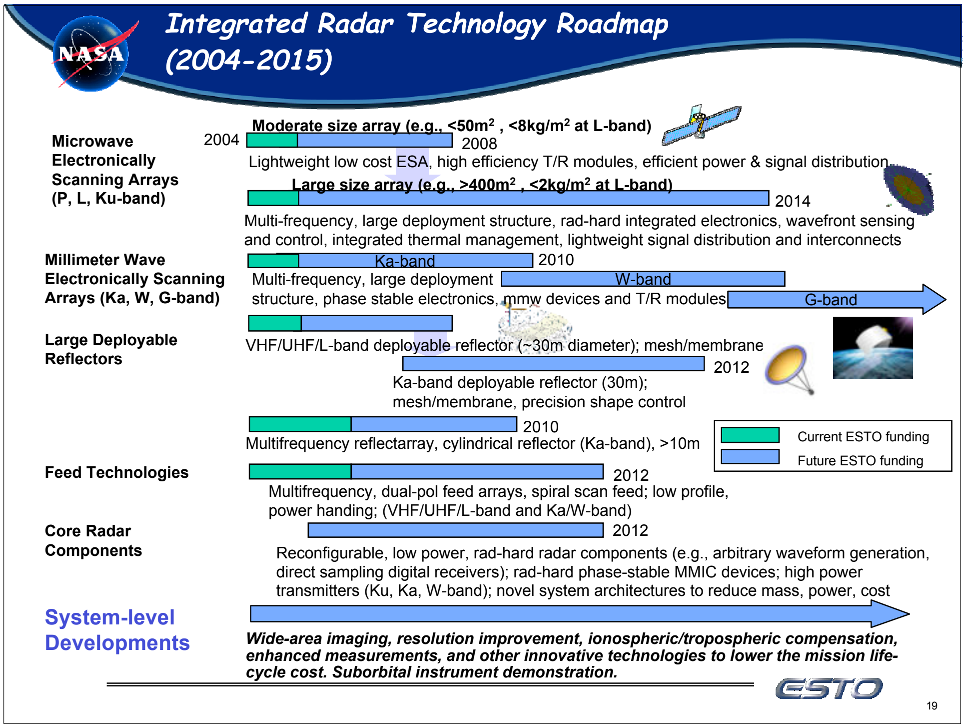

Concluding Remarks

ESTOs Radar/Radiometer Working Group has better defined the technology requirements for ESE key measurement parameters such that future proposal calls (ACT, AIST, IIP) can better solicit for future technologies.

This should enable universities and industry (as well as NASA centers) to propose more competitively.

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BACK-UP SLIDES

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Sample Measurement Classifications

Measurement Class	Criticality	Radar approach	Measurement Parameter	Measurement Scenario
Large Aperture SAR	Enabling	Constellation of L-band geosynchronous InSAR	Surface deformation and stress, Land Surface Topography	46
Large Aperture SAR	Enabling	MEO L-band InSAR	Surface deformation and stress, Land Surface Topography	45
Large Aperture SAR	Enabling	UHF/VHF polarimetric SAR	Soil moisture (deep)	112
Single-Pass Interferometer using phased-array	Enabling	Ka-band along/across track interferometric SAR	River stage height, River discharge rate	100
Single-Pass Interferometer using phased-array	Enabling	Ka-band synthetic aperture altimeter	Ocean surface topography	28
Single-Pass Interferometer using phased-array	Enabling	Ku-band single pass interferometric SAR	Ice surface topography	93
Single-Pass Interferometer using phased-array	Enabling	VHF/Ku-band space and frequency domain interferometic bistatic radar	Sea ice thickness	161A
Single-Pass Interferometer using phased-array	Enabling	X-band single pass InSAR	Land Surface Topography	163
Millimeter Wave Atmospheric Radar using Phased-Array	Enabling	14/35/94GHz Precipitation Radar	Global precipitation	76
Millimeter Wave Atmospheric Radar using Phased-Array	Enabling	14/35GHz Precipitation Radar	Global precipitation	75
Millimeter Wave Atmospheric Radar using Phased-Array	Enabling	35GHz Doppler rain profiling radar	Global precipitation, Storm cells properties	160
Millimeter Wave Atmospheric Radar using Phased-Array	Enabling	94/140GHz scanning cloud profiling radar	Cloud system structure, Cloud particle properties and distribution	159

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Sample Measurement Classifications (cont'd)

Measurement Class	Criticality	Radar approach	Measurement Parameter	Measurement Scenario	Priority
Moderate Aperture SAR	Enhancing	Ka-band single pass interferometric SAR	Sea ice thickness	97	4
Moderate Aperture SAR	Enhancing	Ku/L-band Polarimetric SAR	Snow cover, accumulation, and water equivalent	105	4
Moderate Aperture SAR	Enhancing	L-band dual polarization SAR	Freeze-thaw	22	4
Moderate Aperture SAR	Enhancing	L-band polarimetric SAR	Land cover and land use	162	4
Moderate Aperture SAR	Enhancing	L-band Repeat-Pass Interferometric SAR	Polar ice sheet/glacier velocity	92	4
Moderate Aperture SAR	Enhancing	LEO L-band InSAR	Surface deformation and stress	44a	4
Moderate Aperture SAR	Enhancing	LEO repeat-pass interferometric L-band SAR, quad polarization	Biomass	158	4
Moderate Aperture SAR	Enhancing	P-band polarimetric SAR	Biomass	19	4
Moderate Aperture SAR	Enhancing	Two formation flying LEO L-band SAR	Land Surface Topography	44b	4
Moderate Aperture SAR	Enhancing	Wide-swath Sea Ice Motion C-Band SAR	Sea ice motion and deformation	C1	4
Millimeter Wave Atmospheric Radar	Enhancing	35GHz Differential Frequency Precipitation Radar	Global precipitation	154	5
Millimeter Wave Atmospheric Radar	Enhancing	94GHz Cloud Profiling Radar	Cloud system structure, Cloud particle properties and distribution	142	5
Millimeter Wave Atmospheric Radar	Enhancing	Atmospheric occultation	Atmospheric water vapor, Ozone vertical profile	68	5
MEO Scatterometer	Enhancing	Ku-band polarimetric scatterometer at MEO	Ocean surface winds	148	6

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Sample Measurement Classifications (cont'd)

Measurement Class	Criticality	Radar approach	Measurement Parameter	Measurement Scenario	Priority
Misc. Scenarios	Enhancing	dual freq X-band Delta-k radar at geostationary orbit	Ocean surface current	O2	7
Misc. Scenarios	Enhancing	GPS ground network	Surface deformation and stress, Terrestrial reference frame	51	7
Misc. Scenarios	Enhancing	GPS reflection (L1 and L2)	Ocean surface topography	30	7
Airborne/Suborbital platform	Enhancing	Airborne L-band InSAR	Surface deformation and stress, Land Surface Topography	47	8
Airborne/Suborbital platform	Enhancing	Airborne repeat-pass L-band InSAR , quad-pol	Biomass	157	8
Airborne/Suborbital platform	Enhancing	L/S/C-Band ultra wideband bistatoc radar (formation flying UAV's)	Snow thickness	161C	8
Airborne/Suborbital platform	Enhancing	VHF/UHF ultra wideband bistatic radar (formation flying UAV's)	Sea ice thickness	161B	8
Mature scenario	Mature	Cloud Profiling Radar (94 GHz, constellation of stratospheric long-duration balloons)	Cloud system structure, Cloud particle properties and distribution, Aerosol properties	156	9
Mature scenario	Mature	Dual freq mmw precipitation and cloud profiling UAV radar	Global precipitation, Storm cells properties	155	9
Mature scenario	Mature	Ku-band interferometric altimeter	Ocean surface topography	29	9
Mature scenario	Mature	Ku-band polarimetric scatterometer	Snow cover, accumulation, and water equivalent	102	9
Mature scenario	Mature	Ku-band polarimetric scatterometer	Ocean surface winds	61	9
Mature scenario	Mature	Ku-band real aperture scatterometer	Sea ice extent/motion	90	9
Mature scenario	Mature	Radar for rover	Snow cover, accumulation, and water equivalent, Sea ice thickness	151	9
Obsolete scenario	Obsolete	Ku-band polarimetric interferometric SAR	Snow cover, accumulation, and water equivalent	103	10
Obsolete scenario	Obsolete	Ku-band polarimetric interferometric SAR+L-band polarimetric SAR	Snow cover, accumulation, and water equivalent	104	10

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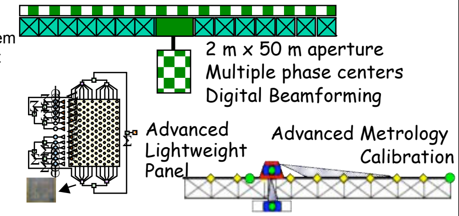
Industry and Other Government Agencies



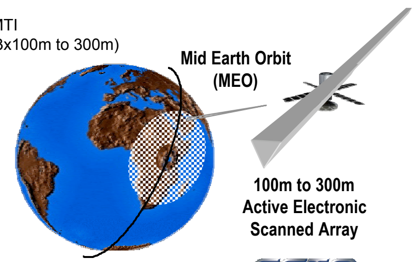
- **AFRL/NASA SBR:** Joint NASA/AFRL program to develop system concept and technologies that can effectively supplement current Air Force SBR developments. This include
  - Advanced lightweight panel development
  - Metrology study
  - Algorithm development

In addition AFRL is developing partially integrated L-band T/R module

- **DARPA:** Several DARPA programs including the Macroelectronics program developing TFT's for large area applications (Low TRL)

-**DARPA's ISAT program:** Large Aperture spaceborne radar for GMTI
  - Inflatable large aperture antenna technology development (3x100m to 300m)
  - MEO constellation concepts
  - RF on flex development, with electronics on rigidized flex and is not flexible

Note: A number of companies are involved in these programs including Raytheon, Northrop Grumman, ILC Dover, L'Garde



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Academic and Industry

Representative listing of academic and industry participation/collaborations

- Radar Remote Sensing:
- Univ. of Michigan, UMass, University of Kansas

- Antennas:
- UCLA, UMass
- Lockheed, Raytheon, NGST, Ball, Harris, ILC Dover, L'Garde, Astro Aerospace, AEC Able, Composite Optics

- High Efficiency Power Devices and Amplifiers:
- Caltech, Univ. of Iowa
- CREE (SiC, GaN), CPI, Thales

- RF IC's, MMIC's, MEMS:
- University of Michigan, Arizona State University, Kansas State University, Caltech, UCLA
- Honeywell, Peregrine, Rockwell, Remec, U.S. Monolithics, NGST, Raytheon

- Packaging/Materials:
- Auburn University, Georgia Tech., Penn State

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Digital Beamforming (DBF)

for large array MEO/Geo SAR applications

Current Status

- **Hardware:** Mixed-signal (ADC) and reconfigurable (FPGA) IC technology at TRL 4-5.
- **Firmware:** Algorithm development at TRL 3.
- **Proof-of-concept demonstrated:** STAR radiometry, SBR, next-generation DSN array (TRL 3-5).

Tasks Needed

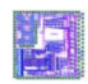
Build a hardware prototype of multi-channel L-band DBF system:

1. Rad-hard, low power, high-speed A/D conversion applied near antenna sub-system (at panel or element level).
2. Distributed microwave coaxial cables replaced with phase-stable digital fiber-optic network.
3. Address SEU immunity using "Rad-Hard by design" techniques

Instrument/Platform Requirements

- **Large antenna:** 20–50 m antenna span (rectangular panel array or circular aperture).
- **Direct RF A/D conversion:** 1.26 GHz carrier frequency, 80 MHz bandwidth, 8-12 bit resolution.
- **High data throughput:** Electronic beam steering, combining >30 phase center channels.
- **Phase stability:** 10–100 millidegree phase precision over wide thermal gradients.
- **On-board processing rate:** 10–100 billion op/s.

2_50 m SAR concept



High-speed GaAs and SiGe ADCs (up to 6 GHz input bandwidth)

High density FPGAs (up to 8 million gates)

Technology path toward single-chip receivers for a SAR array.

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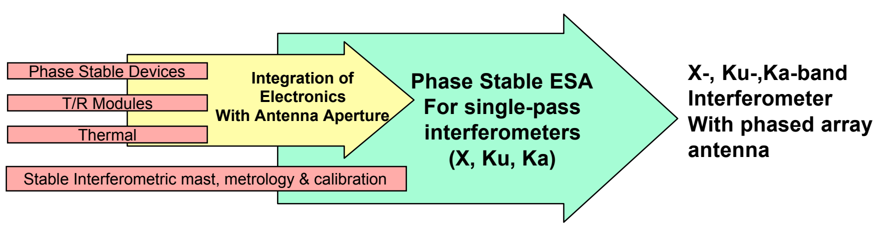
X-, Ku-, Ka-band Single-Pass Interferometers using Electronically Steering Arrays (ESAs)



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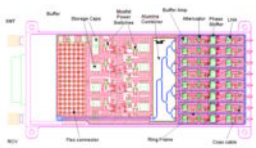
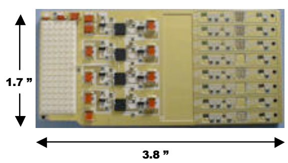
Ka-band T/R Modules

similar roadmap for Ku-band or X-band

Layout of Receive side of
8-channel MSL T/R module



Photograph of receive side of
8-channel MSL T/R module



Current Status:

- 1 W transmit chain, 20% efficiency demonstrated (using Triquint 2W chip) (TRL 3)
- 8-channel LTCC module w/ GaAs MMICs
  - 17 dBm output power, 4GHz BW
  - Low power-added efficiency (low power module)
  - 30 g/channel mass
- Developed under ATIP and Mars Focused Tech Program
  - Multi-module brassboard demonstrated circuitry (TRL 4)
- There are no equivalent commercial products

Tasks needed:

1. Improvement in efficiency to 30% (by 2006) to 50% (by 2010)
2. Increase power to 3W (by 2006) to 10W (by 2010) (Triquint 6W MMIC chip recently available)
3. Address phase stable receive electronics (for interferometers)
4. Further miniaturization and application specific packaging (ie, 2D array)
5. Reduced mass and cost
6. Add BIT and telemetry

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W-band & G-band Devices for T/R modules

MMIC development at 95GHz and 140GHz

Current Status:

- W-band (95 GHz) components:
  - 0.25W PA, 6dB NF LNA
- G-band (140 GHz) components:
  - T/R components (particularly PA) do not exist

Tasks needed:

Basic research to develop new MMIC devices using GaAs, GaN, InP, MEMS (or other emerging semiconductor technologies) at 95 GHz and 140 GHz for future T/R modules

1. Develop MMIC devices such as power amplifiers (PAs), LNAs, Phase Shifters, switches, filters. Performance goals:
   - W-band MMICs: 1W PA with 20% PAE, <4dB NF LNA, 4-bit phase shifter (<3dB loss)
   - G-band MMICs: 0.5W PA with 10% PAE, 6dB NF LNA
2. Develop low loss power combining and packaging technologies at 95GHz and 140GHz for future T/R modules
3. Address the integration of the MMICs for T/R modules

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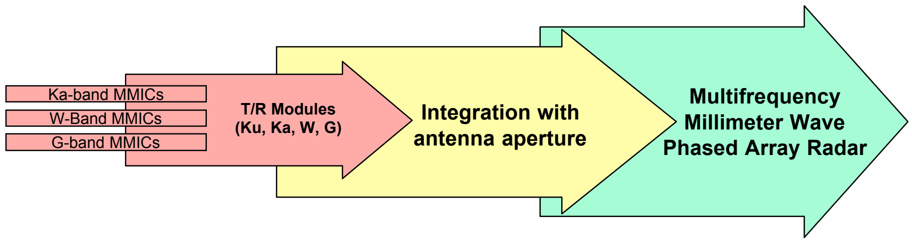
Millimeter Wave Atmospheric Radar using ESAs



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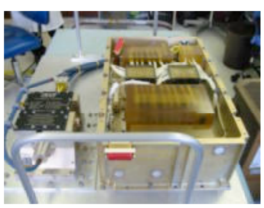
High Power Transmitter Technologies (Ku, Ka, W-band)



Cloudsat
1.5KW EIKA EQM

OVWM/WSOA
120 W TWTA breadboard

Current Status:

- 1.5KW 95GHz EIKA (klystron + high voltage power supply) developed for Cloudsat (TRL >6)
- 120W Ku-band (14GHz) TWTA under development for OVWM and WSOA (TRL 5)

Tasks needed:

- Continue developments of space transmitter tube amplifiers at Ku-band and W-band
  1. Develop a 10KW EIK at 95GHz (W-band) with 20KV HVPS
  2. Develop a >500W TWTA at 14GHz (Ku-band)
- Apply Cloudsat EIKA experience to develop a space-qualified EIKA at Ka-band (35GHz)
  1. Develop a 2-5KW EIK at 35 GHz (Ka-band) with 16-20KV HVPS (based on existing commercial product)

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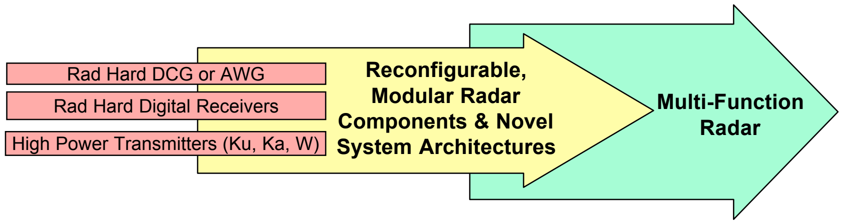
Core Radar Sensor Technologies



- Develop generic and integrated radar building blocks with the flexibility to be adapted to a variety of near and far-term radar applications.
- Includes core back-end components such as digital chirp or arbitrary waveform generators and digital receivers
- Includes high-power tube amplifiers and high voltage power supplies
- Technology challenges radiation-hardening (particularly for for electronics required for phased-array antennas where shielding is limited), reducing mass and power and increasing flexibility
- Also includes new system architectures that can result in significantly reduced mass, power and cost.

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